THE ROLE OF PARAMETRIC MODELLING AND ENVIRONMENTAL SIMULATION IN STIMULATING INNOVATION IN HEALTHCARE BUILDING DESIGN AND PERFORMANCE

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ABSTRACT

The significance of environmental impacts on healthcare building performance is evident in the National Health Service (NHS) annual carbon footprint – estimated to be about 18 million tonnes of CO_2 – representing approximately 3% of England's total carbon emissions. The NHS annual energy expenditure is currently over £429 million which represents approximately 22% of its total carbon footprint. This paper – through case study research – describes how parametric modelling and environmental simulation can be applied for the energy-efficient design of new, and performance evaluation of existing healthcare buildings. Building energy performance evaluation is important and its integration during the design stage is capable of overcoming the energy-efficiency barrier while facilitating low-energy building design by a 50-75% reduction in consumption levels. Parametric modelling and environmental simulation has an important role to play through: strengthening the evidence base; mitigating environmental impacts; assessing innovative solutions; improving collaboration between healthcare building design teams; consensus building among multiple stakeholders; reduction in energy costs; and improvement in occupancy comfort.

KEYWORDS

energy efficiency, environmental simulation, healthcare buildings, innovation, parametric modelling

INTRODUCTION

There is a growing need for healthcare infrastructure to be more sustainable. Sustainable built environments which offer green surroundings can also help improve: the healing environment and patients' rate of recovery (CICA, 2002; SDC, 2005; and Shelbourn et al., 2006); the overall performance of healthcare service through reduced running costs; and user satisfaction through more occupant friendly facilities (Bosch and Pearce, 2003). Designing, constructing and managing a hospital in accordance with principles of sustainable development can also benefit the local community, the economy and the environment. It can also improve public health as well as reduce the demand for health services (Kats and Capital, 2003). However, there have been many missed opportunities regarding the integration and advancement of sustainability to reduce long-term costs of healthcare services (NAO, 2003).

Sustainability assessment needs to take into account economic, social and environmental issues and is critical to any value assessment (SCTG, 2003). Consequently, the design and construction of greener healthcare facilities has to take into account the associated economic costs (HFMA, 2004). Roberts (2004) suggested that the use of advanced technologies of design and healthcare infrastructure could help deliver sustainable healthcare service for communities. However, the impact of technological innovation on the social, economic and environmental dimensions of sustainability is difficult to assess. Also, recent research identified over 600 construction related sustainability assessment tools which can make the selection of an appropriate method difficult for the uninformed user (Walton, et al., 2005).

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According to the National Health Service Sustainable Development Unit (NHS SDU) (2008), the environment and climate change impact significantly on the energy performance of healthcare buildings. This is evident in the National Health Service (NHS) England's annual carbon footprint – estimated to be about 18 million tonnes of CO_2 – which accounts for approximately 3% of England's total carbon emissions and confirms the NHS to be the most significant contributor to climate change within the United Kingdom (UK) public sector. An acknowledgement of the enormity of the challenge, but yet necessity in tackling climate change impacts on healthcare building energy performance and occupancy comfort is evident in 'Saving Carbon, Improving Health', which is a consultation document specifying a draft carbon reduction strategy for the NHS in England. It is aimed at fulfilling two central objectives in the NHS England's fight to mitigate the impacts of climate change. Firstly, the provision of support to all NHS organisations, including its people and partners in order to achieve an organised and sustained approach to carbon reduction within the NHS. Secondly, the establishment of NHS organisations, including its people and partners, as pioneers in the public sector fight against the impacts of climate change. Further, the challenge has been structured into a national target for the NHS in England whereby the aim is to reduce NHS carbon emissions – by as much as 60% – by the year 2050. These are all timely, particularly considering the implications of the significant statistics described in this document. For instance, the environment and climate change could impact on the one million or more patients that are cared for every 36 hours in NHS healthcare buildings. Currently, the NHS annual energy expenditure is over £429 million – for both electricity and heating – which accounts for approximately 22% of its total carbon footprint. The NHS's proposed Carbon Reduction Strategy is – in part an aspiration – which serves as a precursor to a framework and attempts to avert environmental and climate change impacts while reducing the amount of generated CO_2.

It is apparent that the use of an appropriate approach for evaluating pre-occupancy and post-occupancy healthcare building energy performances would offer potential in mitigating these environmental and climate change impacts. One such approach is parametric modelling and environmental simulation.

The study disseminated in this paper is intended to help identify and describe the features and capabilities inherent in the parametric modelling and environmental simulation approach. The main methods used to gather the information include the following:

- the use of literature reviews: for the presentation of the features and capabilities of the parametric modelling and environmental simulation approach, as well as the context that necessitates its application; and
- the use of case study research reporting: for the investigation, identification and collation of evidence of good practice in the application of the parametric modelling and environmental simulation approach. The resultant information will be used to develop an integrated strategy that facilitates energy efficient design of new, and the energy performance evaluation of existing, healthcare buildings.

Pre-occupancy and post-occupancy building energy performance evaluation is important and its integration as a strategy – particularly during the new build design stage – is capable of facilitating improvement in low-energy building design by about a 50-75% reduction in energy consumption levels (Clarke, 2001). This paper has discovered that parametric modelling and environmental simulation has an important role to play in delivering innovative energy efficient healthcare buildings by facilitating: a strengthening of the evidence base of environmental impacts within multiple parameters and variables; mitigation of environmental impacts and climate change; the development of innovative solutions; effective integration and collaborative working between teams; consensus building and collective decision making with various stakeholders; a significant reduction in energy costs; and alleviation of occupancy discomfort.

A review undertaken by this paper – which will also be documented in Osaji (2009) – is of literature related to building energy performance evaluation methods. It has identified two methods and these are: the building energy consumption audit method; and the building energy simulation analysis method**.**

BUILDING ENERGY PERFORMANCE EVALUATIONS

According to Flex Your Power (2007), the ideal way to assess and determine a building's energy performance is to: track its energy profile over a period; establish baseline data; and then undertake a comparative study and benchmarking of its energy performance results. Also, without the establishment of an energy performance baseline, it is difficult for facility managers to establish a building's potential energy savings. Further, it identifies two primary ways for the establishment of baseline data and the assessment of building energy performance. These are:

1. energy consumption audit: this involves the use of an energy audit system for the analysis of historical energy use that takes into consideration: operational modifications; climatic extremities; and other factors that affect building energy use and costs; and
2. energy simulation analysis: this requires the modelling of building energy use – also known as calibrated simulation – also involves the use of complex computer software to predict the building energy use.

THE BUILDING ENERGY CONSUMPTION AUDIT METHOD

As mentioned previously, one of the building energy performance evaluation methods identified by this paper is the building energy consumption audit. It is required for the establishment of baseline energy consumption data, thereby facilitating the assessment of building energy performance. It also involves the analysis of the building's historical energy consumption and other factors capable of influencing its energy costs.

The problem of building occupancy discomfort occurs due to inconvenient indoor thermal conditions, and its resolution is one of the reasons for the adoption of building energy efficiency and energy conservation measures. The building energy consumption audit is capable of tracking building energy performance and comparing this to baseline data for the detection and determination of problems – such as cooling equipment malfunction and other occurrences – that could lead to energy demand surges. Apart from the building energy consumption audit characteristics already described – such as the assessment of building energy performance against a baseline – benchmarking can also be used for comparative analysis against attributes that include: climate; size; operations; and age. This provides an opportunity for a building's historical energy performance to be assessed through a statistical comparison with best practice guidelines, regulations and projections for achievement of energy efficiency.

Apart from the building energy consumption audit, another building energy performance evaluation method is the building energy simulation analysis method.

THE BUILDING ENERGY SIMULATION ANALYSIS METHOD

Building energy performance evaluation is important and Clarke (2001) acknowledges that its integration – particularly during the new build design stage – is capable of overcoming the barrier to accessing the energy efficiency resource potential, thereby facilitating improvement in low-energy building design. It is anticipated such an improvement would translate to a 50-75% energy use reduction that is relative to 2000 energy consumption levels. Its implications include: a significant reduction in state energy costs; contribution to the mitigation of environmental impacts and climate change; and alleviation of occupancy discomfort.

Clarke (2001) recommends building energy simulation analysis as a building energy performance evaluation method because it is capable of overcoming the mentioned barrier that is caused by ineffective decision-support. Building energy simulation analysis overcomes this barrier by facilitating:

- a strengthening of the evidence base of environmental impacts;
- the development of innovative solutions;
- effective integration and collaborative working between teams; and
- consensus building and collective decision making with multiple stakeholders.

Clarke (2001) identifies the benefits of the building energy simulation analysis method as the facilitation of the appraisal of varied energy demand reduction options, best and sustainable practices, and the performance and associated cost of alternative design approaches. Szalapaj (2001) identifies that heating and energy environmental systems are of particular importance to the environmental analyses tasks performed by building energy simulation analysis programs. Also, Szalapaj (2001; 31) indicates that “thermal analysis ranges from simple U-value calculations, through to complex simulations that dynamically model thermal properties”.

Crawley et al. (2005) identifies twenty major building energy simulation analysis programs and these are: BLAST; Bsim; DeST; DOE-2.1E; ECOTECT; Ener-Win; Energy Express; Energy-10; EnergyPlus; eQUEST; ESP-r; IDA ICE; IES <VE>; HAP; HEED; PowerDomus; SUNREL; Tas; TRACE; and TRNSYS. There are also two other simulation programs that have been identified by Osaji (2009), and these are the National Calculation Method (NCM) and Simplified Building Energy Model (SBEM), as well as its user interface – iSBEM (Building Research Establishment (BRE), 2008). However, the ECOTECT building energy simulation analysis program was identified by this paper to possess good features and capabilities that support parametric modelling and environmental simulation.

ECOTECT: A Parametric Modelling and Environmental Simulation Tool

Parametric Modelling and Environmental Simulation can be described as the use of object oriented CAD for the modelling and simulation of components – within multiple real-world behaviours and environmental attributes – in order to assess, evaluate and validate design solutions and ‘what-if’ scenarios. In a review of literature related to over twenty major building energy simulation analysis programs, ECOTECT was identified by this paper to support parametric modelling and environmental simulation.

In its description of the ECOTECT building design and analysis tool, Crawley et al. (2005: 232) identifies that “ECOTECT is a highly visual architectural design and analysis tool…”. It has the capability to link multiple performance analysis functions to a 3D editor and modeller, and its performance analysis functions include thermal, energy, lighting, shading, acoustics and cost aspects. Its 3D editing, modelling, and visualisation capabilities are advanced enough to incorporate varying degrees of volumetric and analytical complexities. Its volumetric and spatial analysis results can be visualised and real time animations can be created to reflect updates and changes to the building’s response to its location, climate, and operational hours’ characteristics. ECOTECT provides the opportunity for obtaining important performance feedback during the earliest stages of the building design process. It displays analytical results as standard graph and table based reports, however, such results can also be mapped over the building surfaces and within their spaces. During studies involving the use and review of ECOTECT by an environmental designer and architect, it was discovered (refer to Table 1) to be a highly visual and interactive tool that supports:

- parametric modelling;
- performance analysis covering thermal, energy, lighting, shading, acoustics, resource use, and cost aspects within multiple environmental parameters;
- mapping of analysis results over building surfaces and within spaces;
- compatibility with EnergyPlus, Radiance, NIST FDS and ArchiCAD; and
- evidence based design improvements.

Table 1. The Adopted Building Energy Performance Simulation Program

Adopted Building Energy Performance Simulation Program	**Reasons**
ECOTECT building design energy performance simulation analysis program	• It supports parametric modelling; • It is a highly visual and interactive building design and analysis tool; • It links a comprehensive 3D modeller with a wide range of performance analysis functions; • It supports performance analysis that covers thermal, energy, lighting, shading, acoustics, resource use, and cost aspects within multiple environmental parameters; • It supports the mapping of analysis results over building surfaces and within spaces; • It supports compatibility with EnergyPlus, Radiance, NIST FDS and ArchiCAD; and • It supports evidence based design improvements, as well as innovative solutions.

THE PARAMETRIC MODELLING AND ENVIRONMENTAL SIMULATION APPROACH: APPLICATION OF ECOTECT

According to Osaji (2009), it was identified that ECOTECT was used for the post-occupancy environmental performance evaluation/assessment of two commercial buildings of similar morphologies and climatic conditions, but of varying height and volume specifications. It employed the use of ECOTECT for the implementation of the parametric modelling and environmental simulation approach – in studying the impacts of multi-variable environmental parameters on these buildings' thermal energy performance – and this involved:

- initially, case study research for the establishment of good practice environmental design details, and for energy consumption audits aimed at the establishment of baseline data: this involved the use of an energy audit system for the analysis of historical energy use (consumption and expenditure) for a particular financial period that took into consideration: operational modifications; climatic extremities; and other factors (key environmental parameters and variables) that affect these buildings' energy use and costs;
- subsequently, environmental performance benchmarking of the audited secondary data against industry standards/ratings. Benchmarking was used for the comparative analysis against attributes that include: climate; size; operations; and age. This provided an opportunity for the buildings' historical energy performance to be assessed through a statistical comparison with best practice guidelines, regulations and projections – such as those of the DETR (2000b) in Wade et al. (2003) – for achievement of energy efficiency; and
- eventually, simulation-based research – involving the use of ECOTECT for parametric modelling and environmental simulations – was undertaken for the study and analysis of the impact of multiple environmental parameters and variables, as well as enablers on the energy performance of the buildings' single and multiple zones for generation of primary data of predictive building environmental performance. The use of ECOTECT for this simulation-based research involved parametric modelling and environmental simulations

of volumetric models (comprising single or multiple zones), which are of similar volume and morphology specifications to the case study buildings.

The environmental simulations – using ECOTECT – of these parametric volumetric models were undertaken for the determination: of the impacts of multi-variable environmental parameters on the buildings' thermal energy performance; and the enablers to a successful building-environmental relationship for thermal energy efficiency.

The parametric modelling and environmental simulations were defined and governed by the following rule set of selected variables:

- building morphology: in terms of the building form as a focus, but also in comparison to similar multiple variable building forms;
- thermal properties: in terms of type of HVAC system (for instance, full air conditioning versus mixed-mode system), comfort band (lower band and upper band), occupancy (number of people and their activity(ies)), internal gains (sensible gain and latent gain), and infiltration rate (air change rate and wind sensitivity);
- building type: in terms of building typology, which is defined by its scale and function;
- site location: in terms of climate zones (for instance, temperate (UK-London, etc.) and tropical (West Africa-Lagos, etc.)), site specifics (north offset, altitude and local terrain), latitude, longitude and local time zone(s);
- building volume: as defined by similar identified in the case study buildings in terms of height specifications of x metres (m) and y metres (m)), and volume specifications of x m^3 and y m^3, where x m = case study building 1's height and y m = case study building 2's height while x m^3 = case study building 1's volume and y m^3 = case study building 2's volume;
- hours of operation: in terms of the weekly staff and public access, as well as their duration of stay and use;
- design conditions: in terms of the clothing, humidity, air speed and lighting levels and conditions; and
- building materials: in terms of the glazing and non-glazing materials, and the U-Value and admittance level.

Based on the thermal energy performance of these multiple case studies, parametric modelling and environmental simulations were undertaken on parametric objects. These parametric objects were of similar volume and morphology to the multiple case studies, but also of comparative morphologies to these same multiple case studies. Environmental simulations of these parametric objects – within a developed rule set – helped determine: the impacts of multi-variable morphological environmental parameters on prolate-like spheroid tall office building thermal energy performance; and the enablers to a successful tall office building morphological environmental relationship for thermal energy-efficiency.

POSSIBLE HEALTHCARE BULDING SCENARIOS THAT PAREMETRIC MODELLING AND ENVIRONMENTAL SIMULATION COULD ASSESS, EVALUATE AND VALIDATE

Parametric modelling and environmental simulation can be used for the modelling and simulation of components – within multiple real-world behaviours and environmental attributes – in order to assess, evaluate and validate design solutions and 'what-if' scenarios. The capability of parametric modelling and environmental simulation to assess, evaluate and validate 'what-if' scenarios is important for both new healthcare buildings, as well as existing ones, including those being subjected to refurbishments.

For instance, one ‘what-if’ scenario that can be assessed evaluated and validated through the use of parametric modelling and environmental simulation is the proposal for the inclusion of more single room accommodation in new hospital designs and what impact this could have on their building services and occupancy comfort.

Although single room hospital accommodation has expected/potential benefits, it should be noted it also raises certain issues that require consideration. A key research question that parametric modelling and environmental simulation possesses the capability to explore is: how can single room hospital accommodation be designed in order to minimise material cost, as well as enable and enhance the patient stay (in terms of occupancy comfort such as thermal comfort)? The more internal walls or partitions that are set-up to create single rooms, the more the need to consider cost and thermal implications.

Parametric modelling and environmental simulation could also address – through the generation of evidence – the choice of an appropriate type of ventilation strategy and control that should be considered for single room hospital accommodation. Should it be centralised or decentralised, independently controlled or otherwise?

Developing and applying suitable lighting strategies becomes more of a challenge when conceptualising single room hospital accommodation. Parametric modelling and environmental simulation possesses the capability to investigate different lighting options in order to determine the most appropriate lighting strategy for single room hospital accommodation while maintaining adequate patient-bed positioning/layout.

The building services that will feed this single room hospital accommodation – and impact on patient and staff comfort – is important. A ‘before’ and ‘after’ scenario that parametric modelling and environmental simulation possesses the capability to investigate is: what is – if any – the difference in building service performance between a single room hospital accommodation and an open plan style ward of similar spatial volume specification? Does an(y) increase in multiple zones within a single zonal volume impact on the building service performance, including on lighting, HVAC, and energy use? In other words, for each single room added to a hospital accommodation, by how much (scheme requirement(s), expenditure and consumption) does it affect the overall hospital accommodation’s building service performance?

CONCLUSION: THE ROLE OF PARAMETRIC MODELLING AND ENVIRONMENTAL SIMULATION IN STIMULATING INNOVATION IN HEALTHCARE BUILDING DESIGN AND PERFORMANCE

This paper has determined that parametric modelling and environmental simulation has an important role to play in stimulating innovation for energy efficient design and performance of healthcare buildings. It does this by facilitating:

- evidence-based design through a strengthening of the evidence of impacts within multiple variable environmental parameters;
- the development of innovative solutions for the mitigation of environmental impacts and climate change;
- effective integration and collaboration between professional teams, and consensus building and collective decision making with various stakeholders; and
- a reduction in energy consumption, expenditure, and occupancy discomfort.

This paper has also determined ECOTECT to be a suitable building energy simulation analysis program possessing capabilities and features that support parametric modelling and environmental simulation for assessment, evaluation and validation of innovative healthcare building design solutions and 'what-if' scenarios. One key 'what-if' scenario is: how can parametric modelling and environmental simulation contribute to meeting the NHS's Carbon Reduction Strategy, and even exceeding its national target to reduce NHS carbon emissions by 60% by 2050 (NHS SDU, 2008).

ECOTECT was discovered to be a highly visual design and analysis tool with the capability to link multiple (thermal, energy, lighting, shading, acoustics and cost) performance analysis functions to an advanced 3D modeller and editor. It permits spatial and volumetric analyses, and real time animations to reflect modifications to the building's responsiveness to parameters such as location, climate, and operational hours. It also offers important performance feedback, including during the earliest stages of the building design process.

These suggest research benefits (refer to Table 2) that indicate the role of parametric modelling and environmental simulation in stimulating innovation, and the attainment of efficiency in healthcare building design and performance.

Table 2. Parametric Modelling and Environmental Simulation Research Benefits
(Clark, 2001; Crawley et al., 2005; Marsh, 1996 and 2006; and Szalapaj, 2001)

BENEFICIARIES	POTENTIAL BENEFITS ARISING
Healthcare building	• Performance analysis covering thermal, energy, lighting, shading, acoustics, resource use, and cost aspects within multiple environmental parameters. • Evidence-based design improvements.
Service users (healthcare building occupants: staff; management; and visitors)	• Optimisation of building performance for improved thermal comfort. • Improved work environments for occupancy comfort and staff productivity. • Improved knowledge of enablers that support care promoting environments.
Practitioners (architects and engineers)	• Parametric modelling for evidence-based design. • Mapping of analysis results over building surfaces and within spaces. • Compatibility with EnergyPlus, Radiance, NIST FDS and ArchiCAD.
Academia	• Evidence of environmental impacts that provide new research opportunities for investigation into their implications for low-energy building design. • Evidence of building optimisation for education and training of practitioners.

These identified benefits will facilitate current research on the fourth work package of the HaCIRIC theme 3 project – 'improving the therapeutic design of healthcare environments through modelling, simulation, and visualisation (MSV)' – which is related to the maximisation of patient (and staff) thermal comfort while minimising energy consumption.

Narayan et al. (2006) have identified that building design are primarily to provide optimised conditions, for human comfort, which include solar control, heating and air-conditioning. Their studies indicated that there is a link between the importance of occupant wellbeing and the need for operational energy efficiency. Studies by Balaras et al. (2006) included a review of operation of hospital HVAC systems and their resulting indoor thermal conditions. It identified the need for energy efficiency while ensuring comfort and overall quality of patient care and services.

Key research questions that this fourth work package seeks to answer include: what is the role of thermal comfort in the therapeutic design of healthcare facilities; and how can thermal comfort and energy performance be optimised? It focuses on the study of the impacts of multi-variable environmental parameters on select built healthcare environments' thermal energy performances. It involves: the literature reviews of current issues and theories relating to environmental impacts, design, and evaluations; the case studies of select UK and international healthcare buildings for environmental design details of good practice; pre-occupancy and post-occupancy energy consumption and performance audits of selected case studies; and energy performance benchmarking of selected case studies against industry standards and NHS targets. It also involves the pre-occupancy and post-occupancy evaluations of selected case studies' and created built healthcare promoting environment (BHE) 3D models' energy performances – within a rule set for multi-variable parametric modelling and environmental simulation – in order to assess 'what-if scenarios' related to varying decisions and targets. It also involves the study of the impacts of variations of the following on healthcare building thermal comfort and energy performance: building morphology; thermal properties (type of HVAC system; percentage level of efficiency of HVAC system; occupancy level; comfort bands; internal gains; infiltration rate; and level of activity); site location (climate zones; local time zones; latitude; longitude; and local terrain); building height; building volume; hours of operation (weekdays; and weekends); design conditions (lighting conditions; humidity; clothing; and air speed); and building materials (type of building materials used; U-Value; and Admittance level).

The main aim of this fourth work package is to develop innovative design solutions that maximise patient (and staff) thermal comfort while minimising energy consumption. The research will also determine and demonstrate how thermal comfort impacts on the clinical outcomes of patients, facility performance and staff productivity. One of the roles that parametric modelling and environmental simulation will play in facilitating the deliverables of this fourth work package is in contributing – as a key MSV input – to the HaCIRIC theme 3's Healthcare Infrastructure Digital Mock Up Facility (HIDMUF). The HIDMUF will be used to: model healthcare spaces, buildings and VR environments; undertake airflow, thermal, energy, and solar exposure simulations of these developed models within multiple-variable environmental parameters; assess, evaluate and validate several design strategies, including in immersive environments; and visualise developed design solutions for the perception of multiple stakeholders.

Theory will be built around the concept of healing/supportive environments and the relationship between thermal comfort, the patient experience and staff performance. The research will determine what new theories and design strategies can be developed from knowledge of the impacts of thermal comfort on patient outcomes. The research will include: a state-of-the-art review for the identification, assimilation and collation of evidence of current UK practice; benchmarking of evidence of UK practice against international best practice; case studies to evaluate evidence of the application and benefits of energy efficiency strategies, as well as solar shading devices and solutions. Parametric modelling and environmental simulation will be undertaken for the performance assessment and validation of evidence based solutions, and the analysis of the energy performance of existing and proposed healthcare buildings within multiple environmental parameters and variables. The research will also link closely to the 'Space Optimisation' project in relation to energy consumption.

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